CLAIMS

What is claimed:

1. A method for measuring phase of light passing through a portion of a sample comprising the steps of:

providing a first wavelength of light;

directing light of the first wavelength along a first optical path and a second optical path, the first optical path extending onto a sample medium to be measured and the second path undergoing a change in path length; and

detecting light from the sample medium and light from the second optical path to measure a change in phase of light passing through two separate points on the sample medium.

2. The method of Claim 1 wherein the medium comprises biological tissue.

3. The method of Claim 1 further comprising at least one of a photodiode array and a photodiode-coupled fiber bundle to image the phase of the sample at a plurality of positions simultaneously.

4. The method of Claim 1 further comprising the step of frequency shifting the light in the second optical path.

5. The method of Claim 1 further comprising the step of detecting the change in phase by at least two photo detectors.

6. The method of Claim 1 further comprising providing a helium-neon laser light source that emits the first wavelength.

7. The method of Claim 1 further comprising providing a low coherence light source.

8. A method for measuring a phase characteristic of light passing through a portion of a sample, comprising the steps of;

providing a first signal and a second signal generated by a first light source and a second light source, respectively, the second light source being a low coherence source;

directing the first signal and the second signal along a first optical path and a second optical path;

varying a path length difference between the first optical path and the second optical path;

generating an output signal indicative of the sum of the first and the second signal with an optical path delay between them;

modulating the output signal at an interferometer lock modulation frequency; and

determining the phase of the sample by the time evolution of the interferometer lock phase.

9. The method of Claim 8 wherein the first signal and second signal are low coherence signals.

10. The method of Claim 8 further comprising demodulating the first signal by using one of a mixer or lock-in amplifier.

11. The method of Claim 8 further comprising electronically generating the interferometer lock phase.

12. A system for measuring phase of light passing through a portion of a sample, comprising:

a first light source that generates a first signal;

an interferometer that generates a second signal with two pulses separated by a time delay from the first signal;

a first optical path from the interferometer in communication with the sample and a second optical path from the interferometer in communication with a reference; and

a detector system that measures a first heterodyne signal from the first and the second signal from the sample and the reference, respectively, and the interference between the light reflected from the sample and the reference; and detecting a phase of the heterodyne signal indicative of the phase of the sample reflection relative to the reference reflection.

13. The system of Claim 12 wherein the first signal is a low coherence signal.

14. The system of Claim 12 wherein the first light source is one of a superluminescent diode and multimode laser diode.

15. The system of Claim 12 wherein the interferometer further comprises a first path and a second path, the second path having acousto-optic modulators.

16. The system of Claim 12 further comprising an optical pathway including an optical fiber.

17. The system of Claim 12 further comprising a low coherence signal having a bandwidth of at least 5 nm.

18. The system of Claim 12 wherein the system comprises a vibration-isolated heterodyne Michelson interferometer.

19. The system of Claim 12 wherein the interferometer further comprises a mirror attached to a translation stage to controllably adjust an optical path length difference.

20. The system of Claim 12 wherein the detector system comprises a first detector that detects a signal reflected from the sample and a second detector that detects a signal reflected from the reference.

21. A method for imaging a sample comprising the steps of:

illuminating a sample, the light originating from a point on the sample having a low frequency spatial component and high frequency spatial components;

interfering along a common optical path the high frequency spatial components with the low frequency spatial component to produce a first intensity signal;

shifting the phase of the low frequency spatial component to produce a first phase shifted low frequency spatial component;

interfering along a common optical path the high frequency spatial components with the first phase shifted low frequency spatial component to produce a second intensity signal;

shifting the phase of the low frequency spatial component to produce a second phase shifted low frequency spatial component;

interfering along a common optical path the high frequency spatial components with the second phase shifted low frequency spatial component to produce a third intensity signal;

shifting the phase of the low frequency spatial component to produce a third phase shifted low frequency spatial component;

interfering along a common optical path the high frequency spatial components with the third phase shifted low frequency spatial component to produce a fourth intensity signal;

generating a phase image of the point on the sample based at least in part on the first intensity signal, the second intensity signal, the third intensity signal and the fourth intensity signal.

22. The method of claim 21, further comprising the step of:

generating a phase image of the sample by repeating the steps of claim 1 for a plurality of points on the sample.

23. The method of claim 21, wherein the step of illuminating comprises illuminating the sample using a transmission illumination.

24. The method of claim 21, wherein the step of illuminating comprises illuminating the sample using a reflective illumination.

25. The method of claim 21, wherein the step of illuminating comprises illuminating the sample by both transmission and reflective illumination.

26. The method of claim 21, wherein the step of illuminating comprises illuminating the sample with a superluminescent light source.

27. The method of claim 21, further comprising the step of controlling the amplitude of at least one of the high frequency spatial components.

28. The method of claim 21, further comprising the step of controlling the amplitude of at least one of the low frequency spatial component and phase shifted low frequency spatial components.

29. The method of claim 21, wherein each step of shifting the phase shifts the phase of the low frequency spatial component by substantially $\pi/2$.

30. The method of claim 21, wherein the step of generating a phase image is based at least in part on the equation.

$$\varphi(x,y)=\arctan\left[\frac{\sqrt{\beta}\cdot\sin[\Delta\varphi(x,y)]}{1+\sqrt{\beta}\cdot\cos[\Delta\varphi(x,y)]}\right],$$

where

$$\tan[\Delta\varphi(x,y)]=\frac{I_{image}(x,y;3\pi/2)-I_{image}(x,y;\pi/2)}{I_{image}(x,y;0)-I_{image}(x,y;\pi)}$$, and

$I_{image}(x,y;\delta)$ is the intensity signal for a point (x,y) on the sample surface generated by interfering the high frequency spatial components with a low frequency spatial component of phase shift δ, and $\beta=I_1/I_0$ represents the ratio between the intensity associated with the high frequency spatial component, I_1, and the intensity associated with the low frequency spatial component, I_0.

31. The method of claim 22, wherein the step of generating a phase image of the sample comprises generating a phase image of the sample with a phase sensitivity of greater than about $\lambda/1000$.

32. The method of claim 22, wherein the sample comprises a biological tissue.

33. The method of claim 23, wherein the sample comprises a semiconductor wafer.

34. A method for non-contact optical measurement of a sample having reflecting surfaces, comprising the steps of:

providing a first light source that generates a first signal;

generating a second signal with two pulses separated by a time delay from the first signal using a dual-beam interferometer;

providing a first optical path from the interferometer in communication with the sample and a second optical path from the interferometer in communication with a reference; and

measuring a first heterodyne signal from the first and the second signal from the sample and the reference, respectively, and the interference between the light reflected from the sample and the reference; and detecting a phase of the heterodyne signal indicative of the phase of the sample reflection relative to the reference reflection.

35. The method of Claim 34 wherein the first signal is a low coherence signal.

36. The method of Claim 34 wherein the first light source is one of a superluminescent diode and multimode laser diode.

37. The method of Claim 34 wherein the interferometer further comprises a first path and a second path, the second path having acousto-optic modulators.

38. The method of Claim 34 further comprising an optical pathway including an optical fiber.

39. The method of Claim 34 wherein the sample is a portion of a nerve cell.

40. The method of Claim 34 wherein the interferometer comprises a vibration-isolated heterodyne Michelson interferometer.

41. The method of Claim 34 wherein the interferometer further comprises a mirror attached to a translation stage to controllably adjust an optical path length difference.

42. The method of Claim 34 wherein the step of measuring comprises a detector system having a first detector that detects a signal reflected from the sample and a second detector that detects a signal reflected from the reference.

43. The method of Claim 34 wherein the sample comprises biological tissue.

44. The method of Claim 34 further comprising providing a microscope to detect mechanical changes in the sample.

45. The method of Claim 44 wherein the sample comprises at least one of a single neuron and cell monolayers.

46. The method of Claim 44 wherein the microscope comprises a bifocal microscope.

47. A fiber optic probe for optically imaging a sample, comprising:

a housing having a proximal end and a distal end;

a fiber collimator in the proximal end of the housing coupled to a light source; and

a graded index lens in the distal end of the housing, the lens having a first and second surface wherein the first surface is the reference surface and wherein numerical aperture of the probe provides efficient light gathering from scattering surfaces of a sample.

48. The probe of Claim 47 further comprising a system comprising mounting the fiber optic probe on a translator stage to perform at least one of two-dimensional phase imaging and three-dimensional confocal phase imaging.

49. The probe of Claim 48 wherein the translator stage comprises a scanning piezo translator.

50. The probe of Claim 47 wherein the numerical aperture of the probe is in a range of approximately 0.4 to 0.5.

51. The probe of Claim 47 wherein the probe images in-vivo biological tissue.

52. A method for non-contact optical measurement of an eye, comprising the steps of:

providing a light source that generates a first signal and a second signal;

providing a first optical path from the interferometer in communication with the eye and a second optical path from the interferometer in communication with a reference; and

measuring a first heterodyne signal with light returning from the eye and the reference, respectively, in response to the first signal and the second signal; and

determining a phase of the first heterodyne signal indicative of the phase of the light returning from the eye relative to the light returning from the reference.

53. The method of Claim 52 wherein the first signal is a low coherence signal.

54. The method of Claim 52 wherein the light source is one of a superluminescent diode and multimode laser diode.

55. The method of Claim 52 wherein the interferometer further comprises a first path and a second path, the second path having acousto-optic modulators.

56. The method of Claim 52 further comprising an optical pathway including an optical fiber.